Comments on NTIA BPL Report 04-413

(By, James K. Boomer, May 17, 2004)

Summary

BPL is a very complex concept that must have an engineering, licensing, and regulatory analysis similar to cellular telephone and wireless systems to resolve all technical, regulatory, and (probable) licensing issues before proceeding. This paper underscores the many presently unanswered questions and unresolved issues.

There are six major unresolved BPL-related variables, all of which are random:

1. Random Variable: Distance between power lines and licensed station antennas

2. Random Variable: Licensed station antenna directivity gain and orientation

3. Random Variable: Directivity gain and BPL power radiated from power lines

4. Random Variable: Licensed station modulation, transmitter output power, and total radiated power from its antenna system.

5. Random Variable: On many occasions, the external noise may be less than the rural Alaskan winter environment shown in Figure 5-2, page 5-13, of the NTIA Report 04-413.

6. Random Variable: A licensed station's operating frequency

FCC regulations forbid unlicensed systems from interfering with licensed stations' operations.

In view of these facts, supported by the information that follows, the present approach to provide broadband capability using the power lines as a transmission medium has major electromagnetic compatibility (EMC) issues that must be resolved *prior to fielding such a system*. Unlike other new concepts, such as cellular telephone and today's wireless systems, the current BPL approach is sadly devoid of the mandatory engineering analysis to prove or disprove the concept *prior to fielding equipment*. Indeed, the current approach is unfortunately an unlicensed "let's try it and see what happens!" proposition. It is an invitation to massive misunderstandings and litigation unless all of the issues are clearly delineated and resolved prior to fielding equipment and systems.

General Comments

Notwithstanding NTIA Report 04-413, "Potential Interference From Broadband Over Power Lines (BPL) Systems to Federal Government Radio Communications at 1.7-80 MHz," several basic key questions and issues regarding BPL interference remain to be addressed. The comments herein address the 1.8-30 MHz frequency range, however, the key basic issues yet unresolved involve the whole 1.7-80 MHz frequency range, and include:

1. BPL must not cause any additional interference to licensed stations beyond the interference these stations currently encounter from power line systems without BPL. Accordingly, how can BPL be implemented to satisfy this requirement?
2. The intent of FCC regulations is for unlicensed devices and systems not to interfere with licensed radio communications. How can BPL implemented to satisfy this requirement?
3. What is the total power output and spectrum of the various BPL signal sets, including any plans for its proliferation?
4. Analysis of EMC must be based on quiet external noise conditions, modern licensed station equipment, antennas, and modulation techniques, because such stations must be able to communicate successfully in this scenario without interference from BPL.
5. In assessing EMC, how do we take into account the myriad of BPL and licensed station antenna systems, equipment, and modulation techniques to verify that BPL satisfies FCC regulations? The power lines to which BPL equipments are connected are radiating antennas.

Technical Analysis

One key element in assessing BPL-licensed station EMC is to clearly establish the required technical criteria. Everything else hinges on this.

Maximum Allowable BPL Interference to Licensed Radio Station Receiving Systems

As noted above, quiet external noise conditions must be assumed because the noise level at any instant is a random variable, and EMC must exist in this environment. For example, there may be EMC when the external noise level is, say, 70 dB above thermal (KT_o), because received interference from BPL may be substantially below, and therefore masked, by this system noise level. However when the external noise is, say, 20 dB above thermal, there may not be EMC because BPL radiated power may cause an excessive increase in the receiving system noise floor.

The noise power output power density from a receiver with no added input noise is:

$$N_o = KT_oF \text{ Watts/Hz} \qquad \text{Equation 1}$$

Where,

N_o=Noise power, Watts/Hz

K= Boltzmann's Constant=1.38×10^{-23} Joule per degree Kelvin

T=Temperature in degrees Kelvin (standard temperature, T_o=290 degrees Kelvin)

F=Receiver noise factor (power ratio)

Since we are ultimately concerned with ratios, we assume the receiver has unity gain, hence the absence of the receiver gain in Equation 1. Clearly, we could include receiver gain in our analysis, but the gain term cancels out, and thus need not be carried along on all calculations.

We are interested in how much the receiver noise level is raised by externally induced noise, because for every dB increase in receiver output noise level, we have a corresponding dB decrease in carrier-to-noise ratio from a desired signal source.

Let us characterize externally induced noise level as $mKT_{o.}$

Then, the receiver output noise power density with this externally induced noise is,

$N_o'=KT_oF+mKT_o=KT_o(F+m)$ Watts/Hz   Equation 2

The increase in receiver output noise power density from the addition of this externally induced noise is,

$N_o'/ N_o= KT_o(F+m)/ KT_oF=(F+m)/F=1+m/F$ Equation 3

Recall that noise factor is a power ratio, whereas noise figure is just ten times the logarithm of the noise factor.

The referenced NTIA Report, Volume I, Figure 5-2, page 5-13, lists external noise data for both noisy and quiet environments. For example, data from the graph in Figure 5-2 show that the noise level associated with a quiet Alaska winter environment is as follows:

Freq. (MHz)	**Noise Level (dBW/Hz)**	**Noise Level (dB-KT_o/Hz)**
1.8	-155	49
3.5	-160	44
7	-165	39
10	-173	31
14/18	-178	26
21/24	-183	21
28	-185	19

Table-1 External Noise Level-Quiet Environment (Data Source: See Text)

The right-hand column in Table 1 is simply the output noise power density referred to thermal (KT_o) in dB. To demonstrate the methodology for specifying the maximum allowable interference from BPL, consider a collocated receiving system with a 6 dB noise figure (noise factor of 3.98), operating at 10 MHz.

From Equation 1, the receiver noise output power density without externally induced noise is:

N_o=KT_oF Watts/Hz

K= Boltzmann's Constant=$1.38x10^{-23}$ Joule per degree Kelvin

T_o=Standard temperature=270 degrees Kelvin

F= Noise factor= 3.98 (power ratio)

Then,

$N_o=(1.38x10^{-23})(290)(3.98)= 1.59x10^{-20}$ Watt/Hz (≈ -198 dBW/Hz)

From Table 1, the external noise at 10 MHz is 31dB-KT_o (31 dB above thermal).

From Equation 3:

$N_o'/ N_o =1+m/F$,

Then,

N_o'/ N_o (dB)=10log (1+m/F)

$m=10^{(db-KT_o/10)}$

Thus for external noise 31 dB above thermal,

$m=10^{(31/10)}$=1258.93,

So, from Equation 3,

N_o'/ N_o (dB)=10log(1+1258.93/3.98)=10log 317.32≈25dB

Thus external noise power density 31 dB above thermal raises the receiver noise power density floor 25 dB.

So, with the above external noise, the receiver noise floor becomes:

N_o'= -198+25= -173 dBW/Hz ($5.01x10^{-18}$ Watt)

For EMC, BPL interference must not raise the licensed station's receiver noise floor more than 1 dB. This requirement stems from the fact that a 1 dB decrease in carrier-to-noise ratio will increase a modern, coded (e.g. convolutional rate one-half code with maximum likelihood soft decision detection) binary phase shift keying (BPSK) data system's bit error rate (BER) more than an order of magnitude, as shown in Figure 1.

Then, with a 1 dB increase, the new noise floor is:

N_o'(dBW)+1 dB=N_o"= -173+1= -172 dBW/Hz (6.31×10^{-18} Watt)

We then calculate the maximum allowable additional noise power density input to the receiver for EMC:

N_{ext}=N_o"– N_o' Watts/Hz=6.31×10^{-18}-5.01×10^{-18}= 1.3×10^{-18} Watt/Hz (-178.9 dBW/Hz)

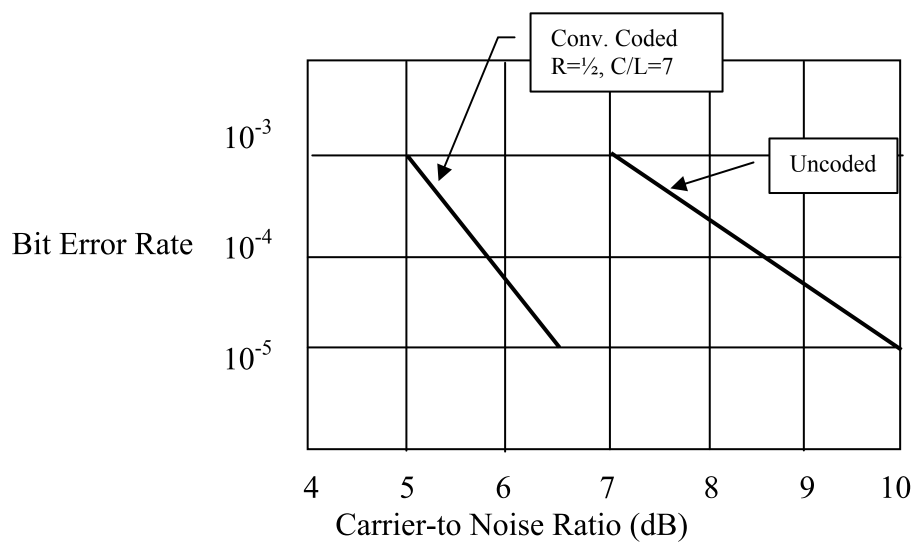

Figure 1-Binary Phase Shift Keying (BPSK) Bit Error Rate vs. C/N Ratio

We use power density in this analysis because in BPL we are dealing with band-limited pseudo-random modulated signals. We can determine the levels in any bandwidth by taking the bandwidth into consideration in the calculations.

Notice in the above analysis, we have not considered the licensed station's receiving antenna, which could have negative directivity gain, or very high positive directivity gain. In addition, we have not characterized the BPL signal power spectra or levels, or the directivity gain of the power lines with BPL signal power applied to them. Finally, we have not discussed the signal energy that BPL systems will receive from licensed station transmitters.

Clearly, there are six major unresolved BPL-related variables, all of which are random:

1. Random Variable: Distance between power lines and licensed station antennas
2. Random Variable: Licensed station antenna directivity gain and orientation
3. Random Variable: Directivity gain and BPL power radiated from power lines
4. Random Variable: Licensed station transmitter modulation, output power, and total radiated power from its antenna system
5. Random Variable: On many occasions, the external noise may be less than the rural Alaskan winter environment shown in Figure 5-2, page 5-13, of the NTIA Report 04-413.
6. Random Variable: A licensed station's operating frequency

From the above analysis, we can calculate field strength by making some realistic assumptions. Then the actual numbers for each scenario can be obtained by making the appropriate corrections.

We have shown that the maximum-allowable BPL interference power density to the licensed station 6 dB noise figure receiver operating at 10 MHz, with external noise 31 dB above thermal, is $1.3\text{x}10^{-18}$ Watt/Hz (-178.9 dBW/Hz).

To calculate field strength, let us assume that the licensed station has an antenna with 0 dBi directivity gain (zero dB directivity gain with respect to an isotropic radiator is a power ratio of 1).

With the received power known, the field strength is given by:

$E_f=(0.2294\text{x}f_{(MHz)}) \text{ x } (P_r/G_r)^{1/2}$ Volts/meter Equation 4

Where,

E_f= Field strength, Volts per meter

$f_{(MHz)}$=Frequency, Megahertz

P_r=Received power, Watts

G_r=Receiver antenna gain (power ratio)

Thus,

$E_f=(0.2294\text{x}10) \text{ x } (1.3\text{x}10^{-18}/1)^{1/2}= 2.62\text{x}10^{-9}$ Volts/meter ($2.62\text{x}10^{-3}$ microvolts/meter) in a 1 Hz bandwidth (-171.6 dB-Volt/meter/Hz)

If we have a receiving system with a 2.8 kHz bandwidth, the maximum allowable field strength is:

E_f=-171.6+10log 2800= -137.1 dB-Volt/meter in 2800 Hz bandwidth

Converting to Volts/meter and microvolts per meter:

$E_f=10^{(dB\text{-}V/m/20)}=1.39\text{x}10^{-7}$ Volt/meter=0.139 microvolt/meter in a 2.8 kHz bandwidth

One popular BPSK mode uses 100 Hz of bandwidth; still another, uses 50 Hz. The maximum allowable field strength in a 100 Hz bandwidth is:

E_f=-171.6+10log 100= -151.6 dB-Volt/meter in 100 Hz bandwidth

Converting to Volts/meter and microvolts per meter:

$E_f=10^{(dB\text{-}V/m/20)}=2.63\text{x}10^{-8}$ Volt/meter=0.0263 microvolt/meter in a 100 Hz bandwidth

If measurement equipment has a 9 kHz bandwidth, the maximum allowable field strength is:

E_f=-171.6+10log 9000= -132.1 dB-Volt/meter in 9 kHz bandwidth

$E_f=10^{(dB\text{-}V/m/20)}=2.5\text{x}10^{-7}$ Volt/meter=0.25 microvolt/meter in a 9 kHz bandwidth

It is important to remember that the above field strength numbers are subject to the six random variables listed earlier.

The above methodology has been used to prepare Table 2, using the Table 1 external noise numbers. Again, all numbers must be adjusted for actual conditions associated with the above five variables. Notice that the Table 2 numbers differ slightly from the above 10 MHz calculation because they are carried out to more decimal places.

Remember that Table-2 assumes that the licensed station antenna has 0dBi gain, which is not the case with many licensed stations. For example, assume we are operating a licensed station on 28 MHz with a 10dBi (power ratio of 10) antenna. From Table-2, the maximum allowable received power from BPL is –190.33 dBW/Hz ($9.27\text{x}10^{-20}$ Watt/Hz). Then, from Equation 4, we have,

$E_f=(0.2294\text{x}f_{(MHz)})\ \text{x}\ (P_r/G_r)^{½}$ Volts/meter=$0.2294\text{x}28\text{x}(9.27\text{x}10^{-20}/10)^{½}$

= $6.18\text{x}10^{-10}$ Volt/meter ($6.18\text{x}10^{-4}$ microvolt/meter), which is 10 dB (voltage ratio of 3.14) less than the number in column 7 of Table-2. In other words, as expected, the maximum allowable BPL interference, when the licensed station is using a 10 dBi directivity gain antenna array, is 10 dB less than is when the licensed station uses a 0 dBi directivity gain antenna.

Freq. (MHz)	Rcvr. N.F. (dB)	Noise Floor, N_o (dBW/Hz)	Ext. Noise (dB-KT_o)	Noise Floor w/Ext. Noise (dBW/Hz)	Max. Allow. BPL Intf. (dBW/Hz)	Max. Allow. BPL Intf. (microvolts/mtr/Hz)	Req'd Max. Allow. Field strength (microvolts/meter/Hz)
1.8	10	-193.98	49	-154.97	-160.84	0.0037	0.00012
3.5	6	-197.98	44	-159.98	-165.84	0.0041	0.00013
7	6	-197.98	39	-164.97	-170.84	0.0046	0.00015
10	6	-197.98	31	-172.94	-178.81	0.0026	0.00008
14	6	-197.98	26	-177.87	-183.74	0.0021	0.00007
18	6	-197.98	26	-177.87	-183.74	0.0027	0.00008
21	6	-197.98	21	-182.65	-188.51	0.0018	0.00006
24	6	-197.98	21	-182.65	-188.51	0.0021	0.00007
28	6	-197.98	19	-184.46	-190.33	0.0020	0.00006

Table-2 Maximum Allowable Field Strength at Licensed Receiver with 0 dBi Antenna (see text)

Antenna modeling reveals that power lines can have substantial directivity gains. One example is shown in Figure 2, which is an azimuth plot of three 10 mm diameter power lines, 340 meters long, spaced 60 cm. apart, and 8.5 meters above the ground. Each line is terminated in 50Ohms at each end, and one outside line is fed at the center. Note that this system has a directivity gain of 9.22dBi at an elevation angle of ten degrees, at right angles to the wire run. So, if the wires are running north and south, the maximum gain will be east and west. Accordingly, the BPL system's transmit power will be magnified by this amount. Additionally, any power received from licensed station transmitters will also be magnified by this amount.

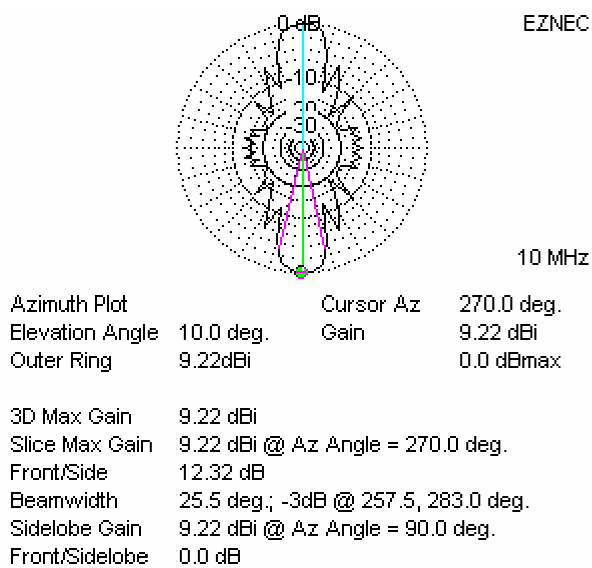

Figure-2 Azimuth Plot, Three 340-meter Long Power Lines (See Text)

It can be shown that some power line runs like the one above have some 15 dBi directivity gain at some frequencies. Additionally, licensed stations have antennas with directivity gains of 15 dB or more. Thus, the allowable field strength at the licensed station should be 30 dB less than the figures in the seventh column of Table 2 in order for us to have a reasonable assurance of EMC. Accordingly, the recommended maximum allowable field strength numbers are shown in the eighth column of Table 2.

The power and field strength numbers in Table 2 are per Hertz of bandwidth. Thus, for example, if one is using a 9 kHz measurement bandwidth, the maximum allowable field strength at 7 MHz is:

$E_{f\ 9kHz\ BW}$=0.00015x $(9000)^{1/2}$=0.0142 microvolt per meter in a 9 kHz bandwidth

Expected BPL Received Power From a Nearby Licensed Station

BPL must endure a challenging EMC environment. For example, consider a 1,000 Watt licensed station operating at 15 MHz, with a 10dBd (dB gain over a dipole) directivity gain antenna array mounted on an 80 ft. tower.

Figure 3 is a set of field strength curves, the data for which are taken from a classic set of ground wave propagation data prepared by Bell Laboratories for the Government in 1946.

Note that the Figure 3 data are based on a 1,000-Watt transmitter with a half-wave dipole ten feet above the ground. To get accurate data for a particular scenario, we utilize correction factors provided by Bell Laboratories.

From Figure 3, at a distance of 0.7 mile, the field strength is 60 dB microvolt/meter. The correction factors to arrive at the actual field strength at 0.7 mile are:

Transmitter antenna height:	+18 dB
Transmitter antenna directivity gain:	+10 dB
Total correction:	+28 dB

Thus the actual field strength at 0.7 mile is 60+28=88 dB microvolt/meter

Converting to microvolts per meter,

$E_f=10^{(\text{dB microvolt/meter}/20)}$ microvolts per meter

From which,

$E_f=2.51\text{x}10^4$ microvolts/meter=0.0251 Volt/meter

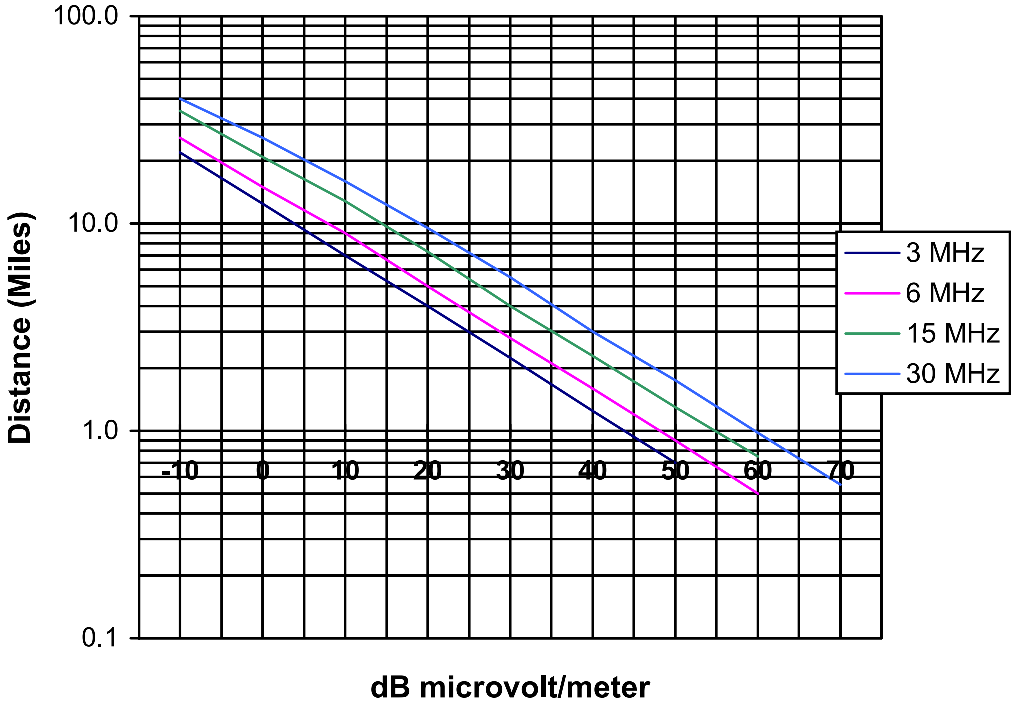

Figure 3- Field Strength vs. Distance 1 KW radiated, Horizontal Polarization, Dipole Antenna, 10 Ft. above Good Soil (Data from Bell Laboratories)

The power received by the BPL system depends upon the gain of the power lines that form an antenna array. The received power is given by:

P_r=18.998xE_f^2xG_r/$f^2_{(MHz)}$ Watts   Equation 5

Where,

E_f=Field strength, Volts/meter

G_r=Receiver antenna gain with respect to an isotropic radiator

$f_{(MHz)}$=Frequency, MHz

If the BPL power lines exhibit 10dBi gain, the received power is:

P_r=18.998x0.0251^2x10/15^2 =5.32x10^{-4} Watt (-32.74 dBW, or –2.74 dBm)

Thus, in the above example, the BPL system will have to operate reliably with an interference level of –32.74 dBW from the above licensed station located 0.7 mile away and operating on 15 MHz. Many HF systems have less than 3 kHz signal bandwidths, however the center frequency can be one of an extremely large number, since modern HF receivers tune in 10 Hz or less increments. Of course, the BPL received power will be larger if the power lines are closer to the licensed station's antenna

Conclusion

The present approach to provide broadband capability using the power lines as a transmission medium has major electromagnetic compatibility (EMC) issues that must be resolved *prior to fielding such a system*.

Unlike other new concepts, such as cellular telephone and today's wireless systems, the current BPL approach is sadly devoid of the mandatory engineering analysis to prove or disprove the concept *prior to fielding equipment*. Indeed, the current approach is unfortunately a "let's try it and see what happens!" proposition. It is an invitation to massive misunderstanding and litigation unless the issues are clearly delineated and resolved prior to fielding equipment and systems.

The current BPL approach has a basic flaw. It is devoid of the required engineering and regulatory analysis that proves or disproves the soundness of the concept. Some preliminary measurements and analysis have been conducted with disagreement among parties on the interference potential of the BPL system.

The American Radio Relay League has identified a realistic scenario:

1. Suppose a person is unable to operate his or her BPL system, and discovers that there is a Radio Amateur living nearby, and that the reason the BPL system isn't working is because of the presence of the Radio Amateur's transmitter signal. Suddenly, we have a human relations issue. The BPL user will rightly claim that he or she is paying for a service that isn't available when the Radio Amateur's station is transmitting. Similarly, the Radio Amateur will rightly claim that his or her equipment meets FCC requirements. The same situation can exist when BPL is interfering with a Radio Amateur's receiver system.
2. In this real world example, the FCC's intent for the BPL supplier to solve the problem seems impractical. For example, in the above scenario, will the BPL supplier come to the BPL user's house during the nighttime and "fix" the above problem? Common sense tells us that this is a "real-time" scenario, where the BPL user and the Radio Amateur both want to use their equipment, and an immediate solution to the problem is virtually impossible.

Clearly, as with all new systems that use radio spectrum, a detailed engineering analysis is mandatory to determine the feasibility of the BPL concept before any decisions are made to field the system. Perhaps today's systems can be called "trials." Then, the engineering analysis can be conducted *before fielding any more BPL equipment*.

Recall that AT&T and NT&T spent years researching the cellular telephone concept before they proved its feasibility. In addition, frequency allocations and FCC regulations and licenses were a major consideration for fielding such a system.

BPL is a very complex concept that must have an engineering, licensing, and regulatory analysis similar to cellular telephone and wireless systems to resolve all technical, regulatory, and (probable) licensing issues before proceeding. As noted earlier in this paper, there are many unanswered questions and unresolved issues.

It is hoped that this paper will help illuminate some of the key BPL issues, and also will help decision makers determine the necessity for objective systematic engineering analysis, as well as frequency allocation analysis to determine the true feasibility of BPL.

James K. Boomer Credentials

- Electronics Engineer, BSEE, 1954 from the University of Nebraska
- Radio and Communication Systems Design Engineer, Staff Engineer and Project Engineer, Collins Radio Company, Cedar Rapids, Iowa, 1954 to 1964
- Communication Systems Project Engineer and Design Engineer for National Cash Register Company, Dayton, Ohio, 1964 to 1966
- Communication Systems Staff Engineer, Design Engineer, Project Engineer, and Engineering Section Manager at Magnavox Company (now Raytheon), 1966-2000